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DEVELOPMENT OF 2-CYLINDER ROTARY COMPRESSOR WITH R-410A

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ABSTRACT

We have developed 2-cylinder rotary compressor with alternative refrigerant R-410A. For higher pressure and higher efficiency, optimization of the compression elements and lubricant was studied. The optimized designs consisted of an oil-film thickness more than the current R22's thickness for journal bearing. COP relative to R-22 was slightly inferior in the high-speed range, but in the low-speed range, a performance equal thereto or more was obtained. For securing the reliability, the vanes and rollers were made of a combination of steel subjected to nitride treatment and alloy cast iron, and HS (Hydrolytically Stable) -POE oil with VG 68 was selected as lubricant. Excellent results were obtained.

INTRODUCTION

It has been determined that designated refrigerant R-22 should be wholly abolished by 2020. Under this situation, we have employed R-410A as an alternative HFC refrigerant for home air-conditioners in consideration of the merits as listed below, and commercialized it.

Merits of R-410A refrigerant

- (1) Its ODP (ozone depletion potential) is zero (0).
- (2) Incombustible, non-toxic, and safe.
- (3) Highly efficient when used for air conditioners.

R-410A has the following problems despite the above merits.

- (1) The load to the compression elements increases because the operating pressure of R-410A is about 1.6 times as that of R-22.
- (2) The theoretical COP of a single compressor lowers due to the properties of the refrigerant.
- (3) Since this is a HFC refrigerant, no chlorine atoms are present, which is disadvantageous in terms of sliding characteristics of the compressor.

In the present Report, problems encountered in the course of development of the 2-cylinder rotary compressor for R-410A and a method for solving the same will be described below.

SUMMARY OF THE PRODUCT

This is a 2-cylinder rotary compressor of inverter-type designed as a heat pump air conditioner having a cooling rated capacity of 4 kW class. Fig. 1 is a sectional view. A DC motor of high efficiency is mounted, and the motor and optimally designed compression elements are secured to a casing which is resistant to high pressure. As lubricant, a polyoester oil originally developed is used.

ENHANCEMENT OF PERFORMANCE (OPTIMIZATION OF DIMENSIONS OF COMPRESSION PARTS)

1. Coping with an increase in shaft load

Fig. 2 shows an analytic result regarding the shaft load when the dimensions of the compression parts are varied. The analysis employed a non-linear axis center analysis program that treats the shaft as an elastic body⁽¹⁾. The suction volume was set to about 70% of R-22. It was seen from the above result that in any specification, the shaft load increases more than in the case of R-22. However, the following were noted:

(1) In case the cylinder bore is 41 mm, the same as R-22, the shaft load decreases as the cylinder height is decreased. However, in this case, the suction intervals are too small, a problem occurs with respect to the pressure resistance of the casing, and a shortage in the tightening length of the cylinder bolts results.

(2) In case the cylinder bore is 39 mm, and the cylinder height is 14 mm, then the shaft load can be suppressed.

Accordingly, the dimensions of the compression parts of the 2-cylinder compressor for R-410A were selected as shown in Table 1 below in consideration of the performance, reliability and mass productivity.

2. Evaluation from minimum oil-film thickness

Also in the selected dimensions shown in Table 1, the load of the sub bearing is about 1.3 times as that in the case of R-22 due to a rise in operational pressure. So, the minimum oil-film thickness at the bearing portion was calculated using the above-mentioned analysis program. It was found that as shown in Fig. 3, an increase of the length of the sub shaft from 16 mm to 20 mm ensures an oil-film thickness equal to the current thickness.

3. Results of study of performance

The performance was evaluated with respect to four conditions in consideration of the operational zone of the inverter compressor. In low speed operation, the compression ratio is set low, and in high speed operation, the compression ratio is set high. The conditions are shown in Table 2⁽²⁾.

Fig. 4 shows the results of measurement of COP in the above-described dimensions including a comparison with the R-22 specification. The following two points were clarified from the results of the measurement.

(1) A difference in COP depending on the specification is hardly seen.
(2) COP relative to R-22 is slightly inferior at 60 r.p.s. or more, but at 30 r.p.s. or less, a performance equal thereto or more was obtained. It is contemplated that COP in the low speed zone was improved for the following two points.

- (1) The leakage loss disadvantageously increases as the differential pressure increases, but by reducing the compression chamber and by reducing the diameter of the crank to reduce the hole in the partition, the roller sealing width can be secured to be wider than before. Further, the viscosity of the lubricant was increased to improve the sealing property. (The leakage loss is reduced.)
- (2) The discharge port provided in the bearing and the discharge volume of the cylinder were reduced. (The re-expansion loss is reduced.)

It is apparent from the foregoing that R-410A is inferior in theoretical COP but the difference from R-22 is reduced than the refrigerant theoretical value due to the optimization, and the present specification exceeds the compressor in the current R22 specification in characteristics.

SECURING RELIABILITY OF COMPRESSOR

(DEVELOPMENT OF LUBRICANT AND DEVELOPMENT OF SLIDING MATERIAL)

1. What's the securing reliability of compressor

Securing of reliance of compressor herein termed is:

- (1) to prevent remarkable lowering of performance (such as efficiency, noises and vibrations), and
- (2) to prevent lowering of safety (such as electric insulating resistance, and pressure resistance).

The causes of the lowering are considered mainly as follows:

- (1) scoring and wear of the sliding portions of the compressor,
- (2) formation of sludge due to the deterioration, reaction and extraction of organic substances or due to wear dust,
- (3) lowering of electric insulation caused by combination of the above (1) and (2), and

(4) fatigue of material of the compressor casing due to cyclic stress.

Regarding the reliability of the compressor as described above, employment of HFC refrigerant, particularly R-410A, is considered to present problems due to deterioration of the slidability caused by the absences of chlorine in the refrigerant or increase in load with respect to the sliding surfaces.

Accordingly, we have judged that for securing the reliability, developments relating to the tribology such as development of lubricant and development of sliding materials are the most important task, and developments have been advanced in accordance with the following three development concepts:

2. Developing concept relating to tribology

2.1 Tribology development concept of compressor

The sliding portion of the compressor was roughly divided into two parts as noted below, and the way of advancing the respective developments was determined.

(a) Fluid lubricating portion

The dimensions for realizing proper load to the sliding portion was designed by the CAE analysis. For realizing the fluid lubrication with the selected dimensions, the development of lubricant having a proper viscosity (particularly, refrigerant dissolved viscosity) was advanced.

(b) Mixed lubrication and boundary lubrication

Attention is paid to the selection of wear-proof materials by wear tests and aircon life tests. The wear evaluation of these tests was made in the following procedure.

(I) Finally, the evaluation is made by an aircon wear test.

(II) A review is made as to whether the conditions of an aircon wear test simulate the actual use conditions.

(III) The endurance must be evaluated by the design life time. In the aircon wear test, we don't to the accelerated evaluation.

(Where evaluation is made in a shorter time than the design life, progress of wear is examined.)

2.2 Concept of development of lubricant

(I) An oil having an actual viscosity (refrigerant dissolved viscosity) necessary for forming an oil film under use conditions is used.

(II) Importance is attached to stability of base oil of the lubricant .

(III) Oilness the lubricant are not excessively evaluated. (The boundary lubrication and mixed lubrication portions are carried out only by the sliding materials.)

2.3 Concept of development of sliding materials

Particularly, with respect to parts constituting the compression elements of the compressor, the respective sliding operations are mutually related so that there are various evaluations of combinations of these materials. Therefore, the development was advanced in the following procedure.

(I) The priority order of selection of combinations of materials is in the order of the boundary lubrication portion, mixed lubrication portion and fluid lubrication portion.

(II) Importance is attached to the balance of combinations of materials.

(III) For selection of materials, the endurance is given priority over the workability.

Among the developments made on the basis of the concepts described above, the following was made apparent. In the actual way of advancement, a table test such as a wear test was made first, the result of which was confirmed by an aircon test. Thus, the results of the aircon test are mainly reported.

RESULTS OF STUDY OF RELIABILITY

1. Study of viscosity of lubricant

For the study of viscosity of the lubricant, polyester oil (POE) and polyether oil (PVE) whose viscosities are VG 32 and VG 68, respectively, are put into a 2-cylinder rotary compressor optimized for R-410A, and an endurance test of the compressor (for 2000 hours) was conducted. A comparison of the results between the fluid lubrication portion, mixed lubrication portion and boundary lubrication portion is given in Table 4. A journal bearing as a fluid lubrication portion has a small wear even with VG32 under the subject condition by an optimum design of dimensions, and is assumed under fluid lubrication except at the time of start of the operation. However, in both the mixed lubrication portion and boundary lubrication portion, VG32 with low viscosity caused an increase in wear, and it has been confirmed that in that area, the viscosity of the lubricant is an important factor for the wear.

2. Study of kind of oil in various lubricants

As the lubricant for the HFC refrigerant, there are POE and PVE as oils having compatibility, and alkyl benzene (BAB) having an extremely low miscibility. A combination of vanes and rollers is set to the following two specifications, and an aircon endurance test of the compressor (for 2000 hours) was conducted. The results are as shown in Table 4.

In the case where both vanes and rollers are made of cast iron, the wear in case of BAB was extremely reduced as compared with POE and PVE. However, in a combination of steel + nitrite treatment (vanes) and cast iron (rollers), wear was very small in any kind of oil. The combinations of materials include a combination in which a difference in wear occurs due to difference in the kind of lubricant and a combination in which no such a difference as described occurs. It was judged that the specification of a combination of steel + nitrite treatment (vanes) and cast iron (rollers) is good from a viewpoint of redundancy.

CONCLUSION

2-cylinder rotary compressor for R-410A as a R-22 alternative refrigerant was developed.

It has been made apparent during the course of development that the following countermeasures are effective with respect to increase in operational pressure as a result of use of R-410A, increase in load, and worsening in sliding conditions.

(1) By optimization of the dimensions of the compression elements and employment of a low viscosity oil, an equal or better performance with respect to the COP ratio relative to R22 was obtained at a low speed range at below 30 r.p.s.

(2) For securing the reliability, the vanes and rollers were made of a combination of steel subjected to nitride treatment and cast iron, and HS-POE oil was selected as the lubricant, thus obtaining a good result.

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- 2) Hayano, M., et al., "Performance Evaluation of 2-Cylinder Rotary Compressor for R-410A", "Proceedings for the International Symposium on R22 Alternative Refrigerants", 1997, PP.169-173.

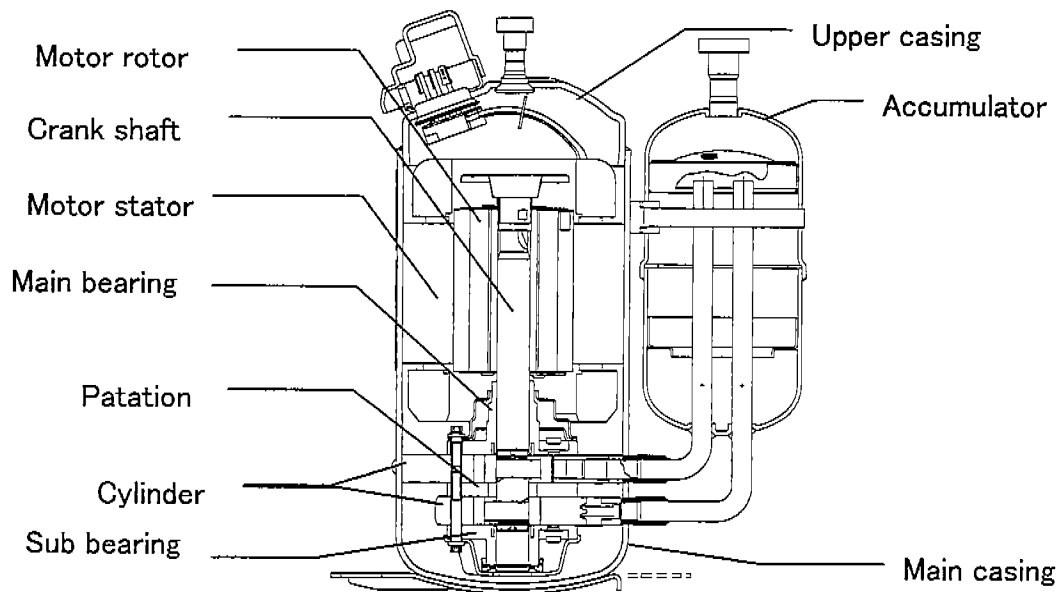


Fig. 1 Corss-section of optimized 2-cylinder rotary compressor

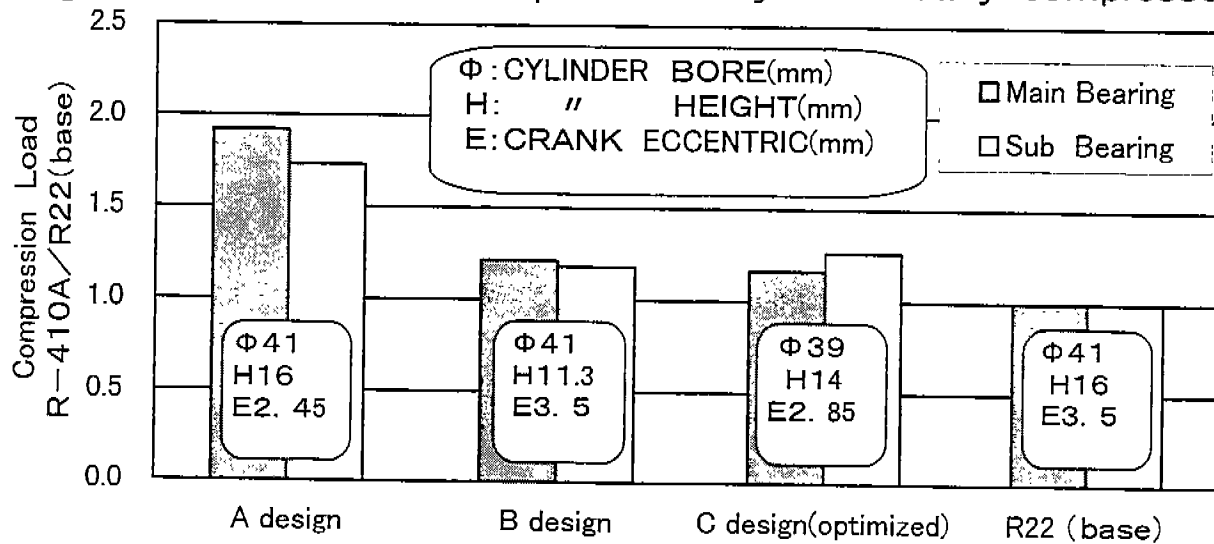


Fig 2. Comparison of Compression Load

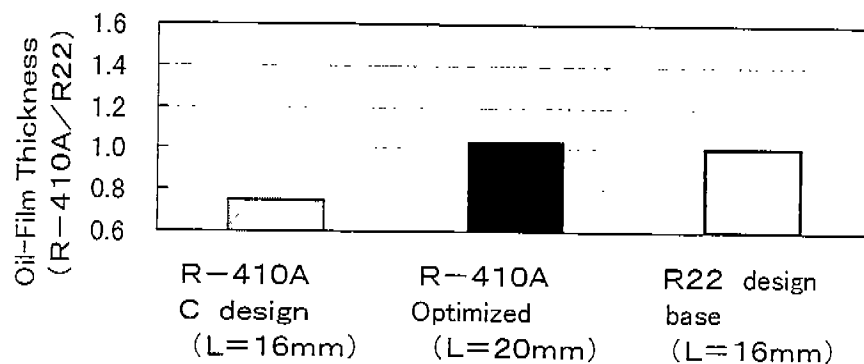


Fig. 3 Comparison of Minimum Oil-Film Thickness for Sub Bearing

Table 1. Optimized Dimensions

Used Refrigerant	Suction volume (cm ³ /rev.)	Cylinder(mm)		Eccentric of Shaft(mm)
		Bore	Height	
R-410A	9.1	39	14	2.85
R-22	13.2	41	16	3.50

Table 2. Test Conditions

Rotational Speed(rps)	Compression Ratio	
	R-410A	R-22
20	1.72	1.73
30	2.05	2.08
60	2.93	2.99
90	4.21	4.32

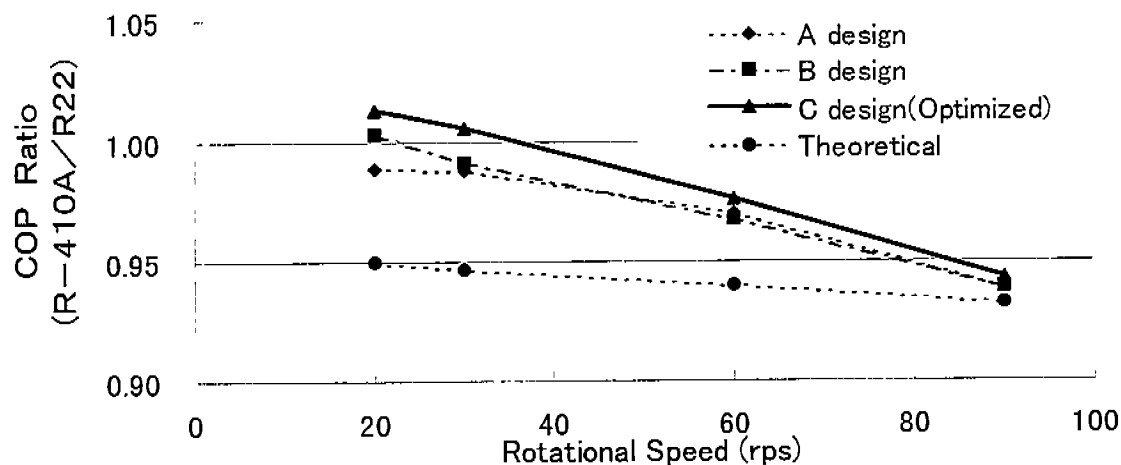


Fig 4. Comparison of Compressor Efficiency

Table 3. Wear of sliding portion on Lubricant V.S. Viscosity

Kind of Lubricant	Lubrication Portion Materials VG	Fluid	Fluid~Mixed	Mixed~Boundary
		Journal	Thrust	Vane/Roller
		Cast Iron /Cast Iron	Steel+Nitride treatment /Cast Iron	Steel+Nitride treatment /Alloy Iron
POE	32	1	3	2
	68 (Selected)	1	1	1
PVE	32	1	3	5
	68	1	1	1

Table 4. Wear of sliding portion V.S. Lubricants
Portion: Vane (Extremity) / Roller

Materials	Cast Iron /Cast Iron	Steel+Nitride treatment /Cast Iron
Lubricant(VG68)		
POE	5	1
PVE	4.5	1
BAB	1.5	1